

Office Note No. 10
On the Question of Development
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For the purposes of the following discussion we can define development as the creation or destruction of absolute vorticity at 500 mb. *But vorticity is conserved*
We shall then examine this problem in the light of an equation for vertical motion. This can be written in the form

$$\frac{\partial^2 \omega}{\partial p^2} + \frac{\alpha s}{f} \nabla^2 \omega = \frac{1}{f} \left[\frac{\partial}{\partial p} (\vec{V} \cdot \nabla \eta) - \nabla^2 (\vec{V} \cdot \nabla \frac{\partial \phi}{\partial p}) \right]$$

where α is specific volume and $s = -\frac{1}{\theta} \frac{\partial \theta}{\partial p}$

Introducing a scale factor K^2 ,

$$\frac{\partial^2 \omega}{\partial p^2} - K^2 \omega = \frac{1}{f} \left[\frac{\partial}{\partial p} (\vec{V} \cdot \nabla \eta) - \nabla^2 (\vec{V} \cdot \nabla \frac{\partial \phi}{\partial p}) \right] = F$$

Broadly speaking, the forcing function, F , of this Helmholtz equation depends on temperature advection, especially when it is considered that the first term, $\frac{\partial}{\partial p} (\vec{V} \cdot \nabla \eta)$, can be decomposed into the two terms

$\frac{\partial \vec{V}}{\partial p} \cdot \nabla \eta + \vec{V} \cdot \nabla \frac{\partial \eta}{\partial p}$. In term of statistical behaviour, F should tend to have large values where the temperature advection is large, and vice versa.

In the special case where F is the same for all values of pressure, integration of the ω equation would give a zero value for $\frac{\partial \omega}{\partial p}$ at the midpoint on the pressure scale. There appears to be no a priori sign of $\frac{\partial F}{\partial p}$ in the atmosphere, since in various synoptic systems temperature advection has strong maxima at either high or low tropospheric levels (e.g. west coast vs. east coast systems). We may then describe three types of regime, characterized by the variation of F with pressure. These are shown schematically in fig. 1, together with the resulting ω curves.

The successful use of 500 mb. data for the barotropic forecast would lead us to believe that on the average atmospheric conditions are represented by Case 2 of Fig. 1, and F is relatively invariant with pressure. However, let us consider three other types of situations, shown in Fig. 2. The first two types may or may not represent trough intensification depending on initial asymmetries, but compared to barotropic forecasts, (a) represents trough acceleration, (b) represents trough retardation, and (c) represents trough intensification.

As far as the above discussion represents atmospheric processes, the question of forecasting development depends on a determination of the variation of F with pressure. Preliminary computations of the

variation of temperature advection with height suggest that this is not a question of a delicate balance, but that pronounced types of $\frac{\partial F}{\partial p}$ occur at different places on the map, and can be easily measured from the reported data.

(definition)

The question then arises: Is it possible to forecast development (as defined above) with a 2-parameter model? In answering this, we can note that three parameters are required for a determination of the sign of the variation of F with pressure. The best one can expect from a 2-parameter model would be:

(a) Some simple assumption regarding the slope of the F curve. Mostly we assume the slope to be vertical, giving a zero value for $\partial w / \partial p$ at 500 mb. We could assume a slope similar to that of case 1 or case 3 for all time and all space. This might yield successful development forecasts for special situations in small areas, but as a general solution, this would be hard to reconcile with our barotropic experience.

(b) Some method of expressing a correlation of $\frac{\partial F}{\partial p}$ with one of the measured or derived parameters. The success of this type of approach would depend on whether or not such a correlation could be established.

The most direct method of computing development appears to require the use of a three-parameter model, in agreement with early statements by Charney. With three observed parameters, one can obtain a one-parameter representation of $\partial F / \partial p$. Previous unsatisfactory experiences with 3-parameter models can probably be interpreted as arising from excessive linearization, excessive or erroneous use of the geostrophic approximation, a neglect of the large-scale divergence of the mean flow, and possibly some difficulty with the finite-difference systems.

George overlooks the probability that fluid systems with dissimilar vertical structures can have similar predictive behavior.

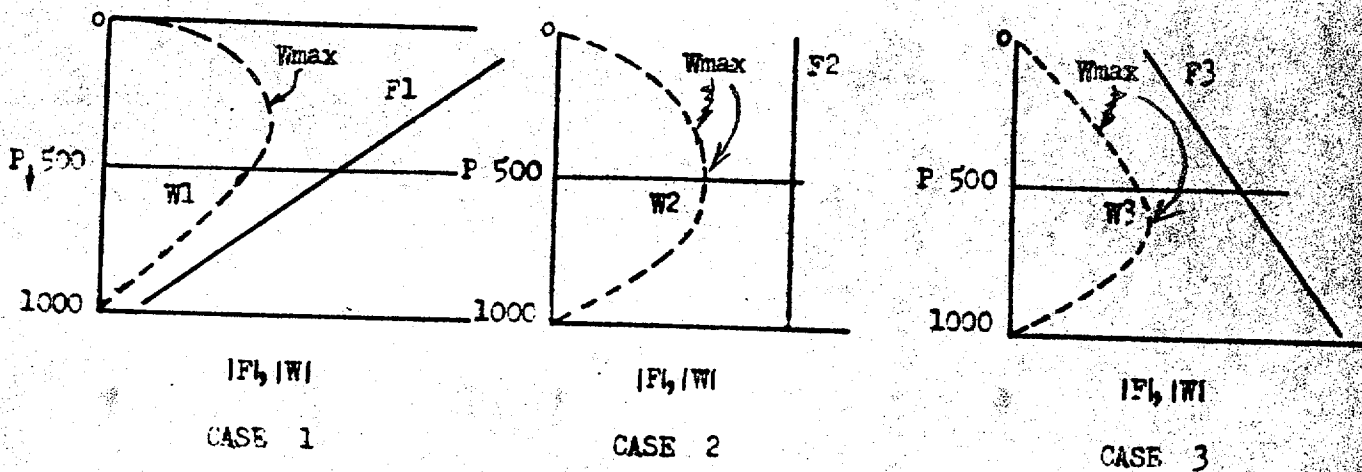
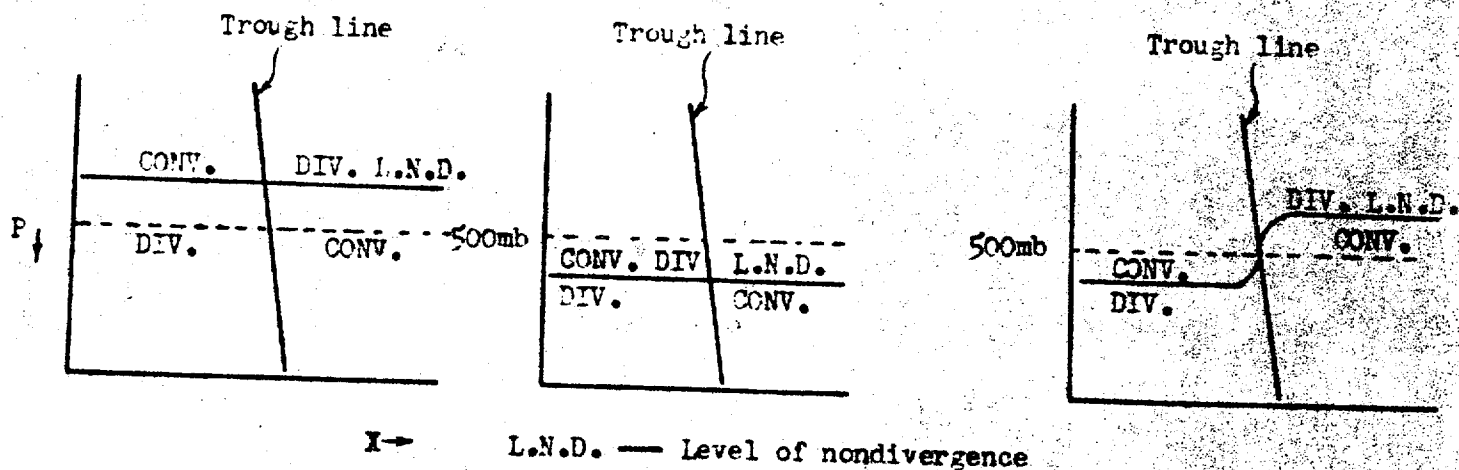


Fig 1. F and W curves of three types.
W=Vertical Motion



a) Case 1 type high-level W_{max} Fast-moving 500 mb trough.

b) Case 3 type Low-level W_{max} Slow-moving, 500 mb trough.

c) mixed type Low-level W_{max} behind trough, High-level W_{max} ahead Development of trough.

Fig 2. Development types